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U.S. Army Redstone Test Center
Building 4500 Martin Road
Redstone Arsenal, AL 36898

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**14. ABSTRACT**
This Test Operations Procedure (TOP) provides guidance on how to perform wind testing. These procedures provide a general basis for testing and should be tailored to the specific test requirements and wind testing facility capabilities. When testing large structures, such as towers, the structural analysis team should be an integral part of the test team for specifying data requirements and supporting structural model validation and verification.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 06-2-301 — 14 June 2017
DTIC AD No.

# WIND TESTING



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1. SCOPE.

a. General.

This Test Operations Procedure (TOP) provides general guidance on how to perform wind testing. These procedures are a general basis for testing and should be tailored to the specific test requirements and wind testing facility capabilities.

b. Limitations.

The procedures in this TOP pertain mainly to wind testing tower structures, but could be adapted for other test items or commodities. Due to the need to specify data requirements for supporting structural model validation and verification the structural analysis team should be an integral part of the test item.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

| Item | Requirement |
|---|---|
| Wind Generation System | The wind generation system, typically consisting of a fan, fan speed control, ducting, and support structure to provide the wind speeds required by the system under test. The speed control may be provided by a variable throttle or variable frequency drive to provide the required variations in wind speeds. Ducting is often required to improve wind speed uniformity and increase wind speed. |

2.2 Instrumentation.

| Devices for Measuring | Permissible Measurement Uncertainty |
|---|---|
| Wind Speed | Wind speed 0-15 meters per second (m/s): ± 0.5m/s.<br>Wind speed greater than 15 m/s: ± 4%. |
| Wind Direction | ± 4 degrees |
| Test Item Loads | The accuracy should be driven by the analyst that will be utilizing the data post-test. At a minimum, the accuracy should be known and incorporated into the stop test conditions. |

| Devices for Measuring | Permissible Measurement Uncertainty |
|---|---|
| Test Item Deflections / Dynamic Response | The accuracy should be driven by the analyst that will be utilizing the data post-test. At a minimum, the accuracy should be known and incorporated into the stop test conditions. |
| Temperature | Accuracy to within ± 1 °Celsius (°C) (1.8 °Fahrenheit (°F)). |
| Humidity | Accuracy within ± 3% (local meteorology data may be used). |

3. REQUIRED TEST CONDITIONS.

3.1 Wind Speeds.

a. Wind speed requirements should be determined based on the planned deployment environment of the test item. These requirements may be captured in the system specification. Military Standard (MIL-STD)-810G CN1[1**], Part III, Section 5.1, provides wind speed information useful in developing wind speed requirements. Similar information is found in Military Handbook (MIL-HDBK)-310C[2], Section 5.1.

b. The required wind speed may increase across the height of the test item to simulate ground boundary layer effects on the wind. This should be defined in the test plan.

c. To determine steady state wind speeds, measurements should be averaged over at least a 10 second interval. Sampling rates should be equal to or greater than one sample per second. To characterize the turbulent nature of the wind field, much higher sampling rates are required. In addition to temporal averaging of the data, spatial averaging should be performed over the predefined test cross sectional area.

d. Simulated wind gusts may be required. The duration and speed of the gust should be specified in the test plan. Typically, the gust duration is 2-3 seconds. Additional details for wind gusts are provided in MIL-STD-810G CN1 and MIL-HDBK-310C.

3.2 Wind Direction.

a. The wind direction should be perpendicular to the faces selected for exposure. If testing is performed outdoors, cross winds can change the wind plume. To mitigate cross wind influences testing should be performed during times with minimal wind. Instrumentation should be placed on or near the test item to ensure that the required wind exposure is being provided. Cross winds will typically result in the generated wind field being moved off the test item resulting in decreased wind speeds at the test item.

** Superscript numbers correspond to Appendix B, References.

b. The item geometry will influence the requirements for the wind direction tolerance. For example, if the item is symmetrical, the wind direction is not as critical. If the intent is to expose a face of the test item that has a large effective projection area, it will tighten the required wind direction tolerance.

3.3 Wind Speed Uniformity.

When the geometry of the test item is large and/or complex, the more difficult it is to provide a uniform wind speed over the test cross sectional area. The tester should employ the wind generation equipment (fans, wind straighteners, ducting) to provide the best uniformity results over the test item. Feasible peaks in the wind speed map should be co-located with the portions of the item that have the largest wind sail or are of the greatest concern. Over the critical areas of the test item, the uniformity of the wind speeds (measured with a minimum of 10 seconds of averaged data) should be ± 15%.

3.4 Wind Turbulence.

Efforts should be made to characterize the wind turbulence spectrum provided by the wind generation system. The objective is to replicate the turbulence characteristics of the atmospheric boundary layer. The turbulence characteristics are described in the Engineering Science Data Unit (ESDU) Data Item 82026[3] (Strong winds in the atmosphere boundary layer) and ESDU Data Item 85020[4] (Characteristics of atmospheric turbulence near the ground). In the operational environment, the wind turbulence is affected by weather, topography, and nearby surface features (trees, buildings, etc.). In simulated wind testing, the wind turbulence can be affected by protuberances both active and passive, fan speed variations, and atmospheric conditions.

3.5 Test Item Faces.

When testing to demonstrate the ability of the tower to safely withstand high wind loads, the worst case tower configuration and the direction of wind exposure should be carefully considered. This should include maximum payload weight, effective projection area, and structural support orientation (i.e., guy wires, support beams, ground contact points).

4. TEST PROCEDURES.

4.1 Wind Field Calibration.

The calibration of the wind field is critical to ensure that the test item is exposed to the required wind speeds. This may be an iterative process as the fan blade pitch, fan speed, duct size, and distance from the fan can all be adjusted to influence the wind speeds. Typically, after the fan and duct configuration is set, the fan speed is the variable that is adjusted to reach the required velocities. Calibration runs with a range of fan speeds are performed and a correlation is made between the fan speeds (or drive setting) and the wind velocities. This correlation will be used during the test to set the wind velocities.

4.2 Wind Field Characterization.

Providing the proper wind speeds over the critical locations of the test item is necessary for a valid test. To ensure that these wind speeds are provided, the wind field generated by the fan system should be characterized. This characterization is typically performed by taking an array of wind velocity measurements at a set spacing (0.3 m (1 foot (ft)) typical, 0.6 m (2 ft maximum)). This wind field characterization may be utilized in the post test analysis to predict the wind load applied to each area of the test item.

> **Note:** In the event that the tower height makes characterization unfeasible at upper heights, the characterization can be performed using a portion of the fans at ground height. This is the method that will likely be employed if the tower is over 30 feet tall.

4.3 Safety.

a. A progression of increasing wind speeds should be utilized to characterize the response of the item under test. This gradual ramping of wind speeds is important to ensure a safe operation of the test item and wind generation equipment assuring that the following safety risks are mitigated:

(1) Tip over of the tower (test item) – measurement of reaction forces. These include monitoring the forces on the guy wires and the load on the contact points with the ground. If the guy wire tension is nearing its structural limit, testing should be aborted. If the load cell at the contact point registers no load, this could indicate high potential for tip over.

(2) Tip over of the fan tower – safety mitigation actions should be performed to ensure that the fan tower is stable during the test operation. These should include a stress analysis of the tower structure to confirm it will sustain the structural loading. Also, mitigating actions such as load cells on the guy wires should be employed to monitor the stability of the tower.

b. Operation of the wind generation equipment can result in high noise levels requiring ear protection. Eye protection should also be utilized to protect from blowing particles.

c. When erecting the tower ensure that all proper procedures are utilized and that the appropriate personal protective equipment (PPE) is utilized. Consult the appropriate technical manuals and safety documentation.

d. If military personnel are required for testing, determine if Military Occupational Specialty (MOS) qualified Soldier-Operator/-Maintainer Test and Evaluation (SOMTE) personnel assigned to the U.S. Army Test and Evaluation Command (ATEC) are available to support the testing. If SOMTE are not available, ensure a Test Schedule and Review Committee (TSARC) request is submitted one year prior to the start of testing, or as early as possible. A Safety Release (SR) must be obtained from the U.S. Army Evaluation Center (AEC) prior to using military personnel as test participants.

4.4 Test Configurations.

Test configurations should be stated in the test plan. The test item configurations, at a minimum, will include the orientation of the test item with respect to the wind field. In some cases, symmetry may be utilized to reduce the number of test orientations. Facility limitations may also need to be taken into account when determining the test orientations. Finally, engineering judgment or structural analysis may be utilized to ascertain the orientations that the test item is most susceptible.

4.5 Test Procedure – Wind Exposure.

Based on the test item requirements and the test objectives, determine the wind speed test points for each configuration determined in paragraph 4.4. Typically these test points are 2.2-4.5 m/s (5-10 miles per hour (mph)) apart and begin at a reasonable low velocity. For example, see Table 1. Depending on the height of the item, test points may be further described by the height location of each fan. Table 2 provides an example.

TABLE 1. TEST POINTS (EXAMPLE 1)

| TEST POINT | TEST ITEM CONFIGURATION 1 m/s (mph) | TEST ITEM CONFIGURATION 2 m/s (mph) |
|---|---|---|
| 1 | 13.4 (30) | 15.6 (35) |
| 2 | 17.9 (40) | 20.1 (45) |
| 3 | 20.1 (45) | 22.4 (50) |
| 4 | 22.4 (50) | 24.6 (55) |

TABLE 2. TEST POINTS (EXAMPLE 2)

| TEST POINT | FAN 1 m/s (mph) | FAN 2 m/s (mph) | FAN 3 m/s (mph) | FAN 4 m/s (mph) |
|---|---|---|---|---|
| *FAN LOCATION* | *(Center 1.1 m (3.5 ft) above the ground)* | *(Center 3.2 m (10.5 ft) above the ground)* | *(Center 5.3 m (17.5 ft) above the ground)* | *(Center 7.5 m (24.5 ft) above the ground)* |
| 1 | 14.3 (32) | 15.6 (35) | 16.5 (37) | 17.0 (38) |
| 2 | 16.1 (36) | 17.9 (40) | 18.8 (42) | 19.7 (44) |
| 3 | 18.3 (41) | 20.1 (45) | 21.5 (48) | 21.9 (49) |
| 4 | 20.1 (45) | 22.4 (50) | 23.7 (53) | 24.6 (55) |

a. Checkout and calibrate the test item instrumentation. Verify that all measurements are recording data properly.

b. Place the test item in the first configuration and install instrumentation.

c. Perform a detailed visual inspection of the test item. Photograph the test item configuration and instrumentation. Document any anomalies.

d. Note the baseline load cell measurements, both on the test item and the fan assembly. These shall be monitored throughout the wind exposure.

e. Start recording data at the required sampling rates.

f. Apply the wind speeds for test point 1. Hold for a minimum of 5 minutes after the fans have reached steady state. Monitor the test data real time, specifically the safety critical loads (see Section 4.3.a). Monitor visually the tower response throughout the exposure.

g. Power down the wind generation equipment. Stop recording data.

h. Perform a detailed visual inspection, noting any signs of damage or permanent deflection. Pay special attention to structural welds, structural members, lifting straps, or other test item features that may impact performance or safety. Photograph the test item. Note any anomalies. Prior to proceeding, all relevant anomalies should receive a safety disposition from the test director.

i. Repeat steps 4.5.d through 4.5.h until all test points have been completed, or the test item limits are reached. If a lapse in testing occurs, perform step 4.5.c as needed.

## 5. DATA REQUIRED.

The following data are typically required:

a. A complete record of wind speed, wind direction, temperature, and humidity over the time period of each wind exposure.

b. A wind map of the test cross sectional area at a minimum of a 0.6 m x 0.6 m (2 ft x2 ft) resolution.

c. Calibration information for the instrumentation.

d. Pre and post wind exposure photographs documenting the test configurations and test item condition.

e. Video documentation of the wind exposures. If available, specialized video and laser positioning tools may be used to determine the test item deflections.

f. A complete record of test item instrumentation measurement data over the time period of each wind exposure. This includes loads, deflections, acceleration and any other data that are required to support post-test analysis.

## 6. PRESENTATION OF DATA.

The presentation of data is often dependent upon how the post-test analysis will be conducted. Data can be presented as contour maps, plots, charts, tables, etc., and all data product formats should be determined prior to test start by the test officer, evaluator, and customer. An example of a wind speed contour map is shown as Figure 1. An example of a tower measurements vs. test conditions is shown as Table 3. The tower measurements will be dependent on the test item.

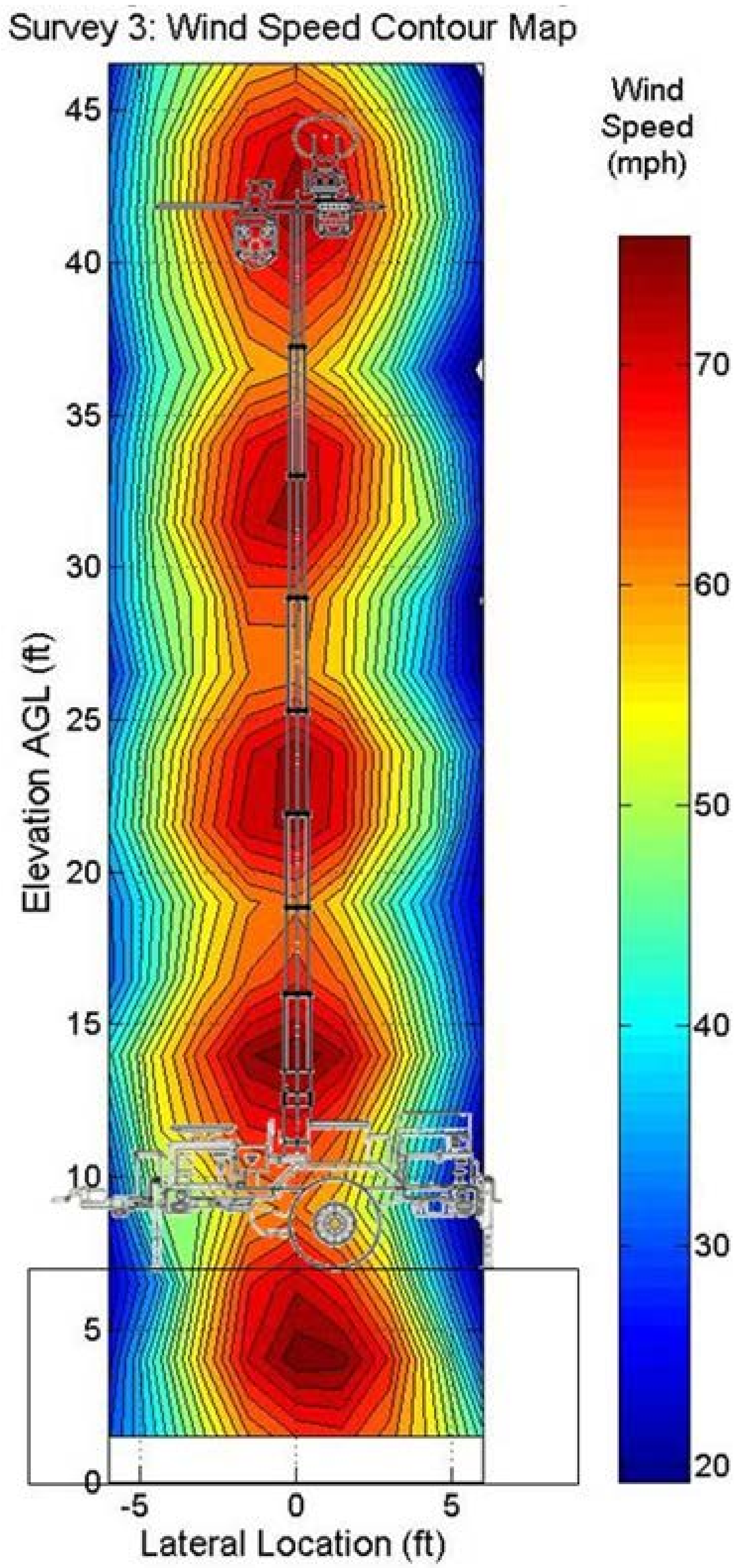


Figure 1. An example of a wind speed contour map

TABLE 3. PRESENTATION EXAMPLE OF TOWER MEASUREMENTS VS TEST CONDITIONS

| FACE EXPOSED | WIND SPEED m/s (mph) | TOWER PAYLOAD DEFLECTION cm (inch) | PEAK LOAD ON GUY WIRE 1 pounds | PEAK LOAD ON GUY WIRE 2 pounds |
|---|---|---|---|---|
| Configuration 1, Face 1 | 17.9 (40) | 3.18 (1.25) | 600 | 400 |
| | 22.4 (50) | 3.81 (1.50) | 624 | 410 |
| | 26.8 (60) | 4.45 (1.75) | 640 | 421 |
| Configuration 2, Face 1 | 17.9 (40) | 2.54 (1.00) | 500 | 430 |
| … | … | … | … | … |

# APPENDIX A. ABBREVIATIONS.

| | |
|---|---|
| °C | °Celsius |
| °F | °Fahrenheit |
| | |
| AEC | U.S. Army Evaluation Center |
| ATEC | U.S. Army Test and Evaluation Command |
| | |
| cm | centimeter |
| | |
| ESDU | Engineering Science Data Unit |
| | |
| ft | foot/feet |
| | |
| m | meter |
| m/s | meters per second |
| MIL-HDBK | Military Handbook |
| MIL-STD | Military Standard |
| MOS | military occupational specialty |
| mph | miles per hour |
| | |
| PPE | personal protective equipment |
| | |
| SOMTE | Soldier-Operator/-Maintainer Test and Evaluation |
| SR | Safety Release |
| | |
| TOP | Test Operations Procedure |
| TSARC | Test Schedule and Review Committee |

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# APPENDIX B. REFERENCES.

1. MIL-STD-810G w/Change Notice 1, Department of Defense Test Method Standard, Environmental Engineering Considerations and Laboratory Tests, 15 April 2014.

2. MIL-HDBK-310, Department of Defense Handbook, Global Climatic Data for Developing Military Products, 23 June 1997.

3. ESDU Data Item 82026, Strong winds in the atmosphere boundary layer. Part 1: mean-hourly wind speeds, 1982.

4. ESDU Data Item 85020, Characteristics of atmospheric turbulence near the ground. Part II: single point data for strong winds (neutral atmosphere), 1985.

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APPENDIX C. APPROVAL AUTHORITY.

CSTE-TM 14 June 2017

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 06-2-301 Wind Testing, Approved for Publication

1. TOP 06-2-301 Wind Testing, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP provides guidance on how to perform wind testing. These procedures provide a general basis for testing and should be tailored to the specific test requirements and wind testing facility capabilities. When testing large structures, such as towers, the structural analysis team should be an integral part of the test team for specifying data requirements and supporting structural model validation and verification.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

HUBNER.MICHAEL.WINFRIED.1042880147

MICHAEL W. HUBNER
Associate Director, Test Management Directorate (G9)

FOR

RAYMOND G. FONTAINE
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: U.S. Army Redstone Test Center, Building 4500 Martin Road, Redstone Arsenal, Alabama 36898. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.